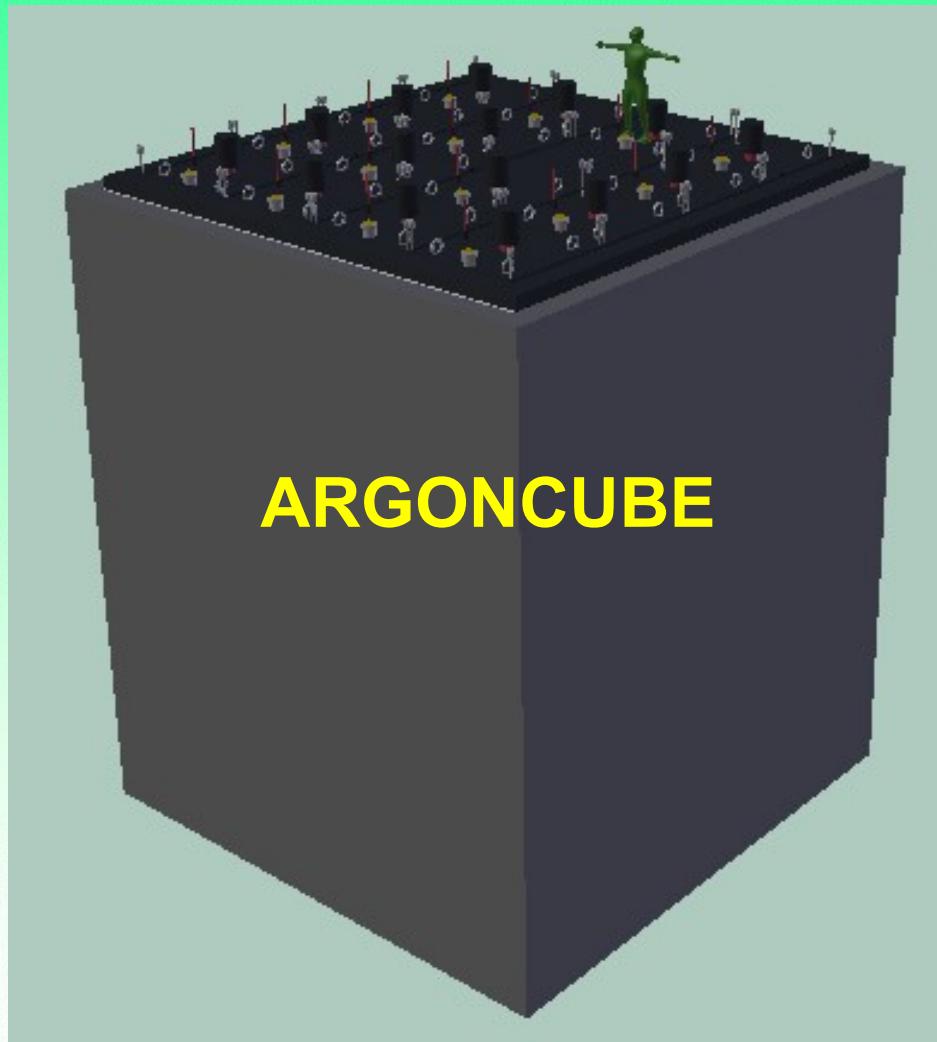
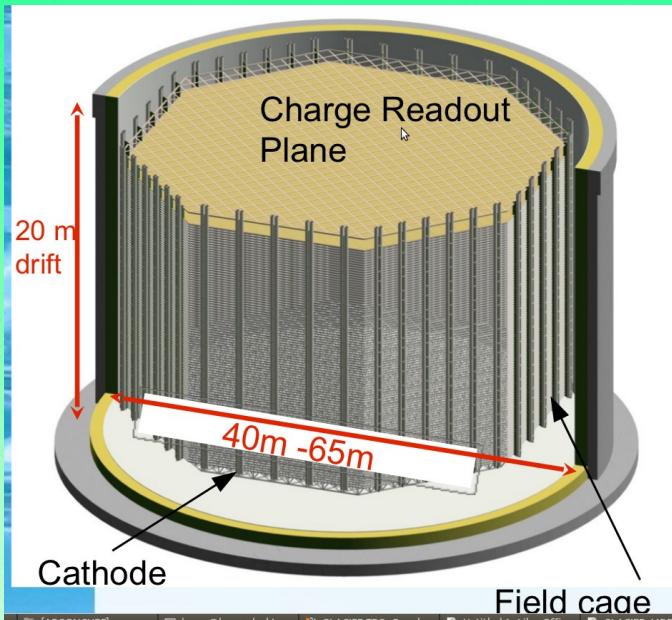


Modular scalable TPC for neutrino observatories

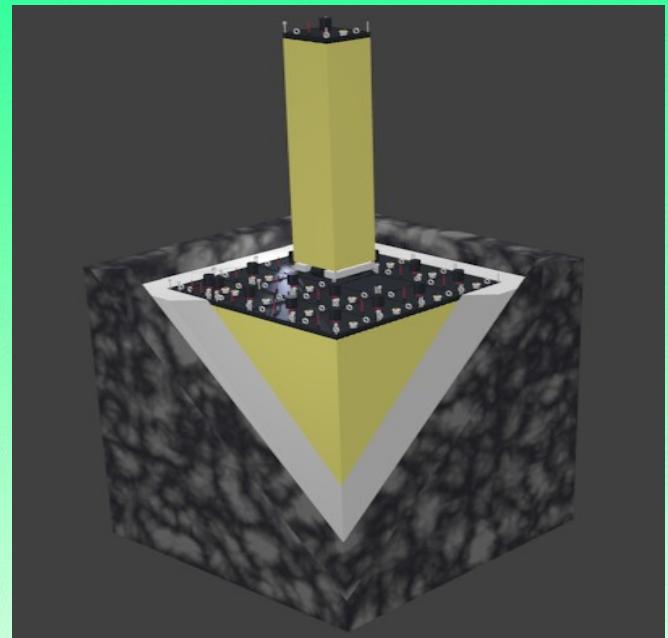


Reference data



GLACIER highlights (for reference)

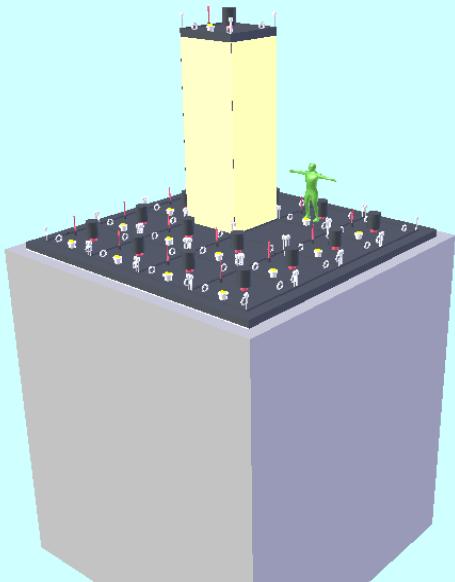
- Single 30 kton argon volume
- 20 kton active (70%)
- Vertical electron drift
- Double-phase charge amplification
- Single drift readout ~ 10-20 ms
- Cathode potential ~1-2 MV



ARGONCUBE (design goals)

- Total 30 kton argon volume, split by ~50 ton modules
- 29 kton active (97%)
- Horizontal electron drift
- Charge amplification by cryogenic electronics
- Cathode potential ~100 kV

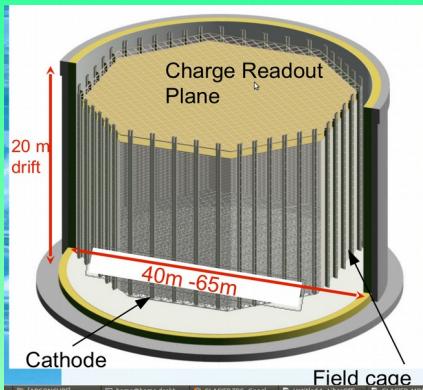
Highlights of modular approach



ARGONCUBE

- Transportable modules
- Unified modules → high redundancy
- Step-by-step commissioning
- Extract module → Repair → Re-insert
- Scalable and extendable (same tech. for ND and FD)
- Iterative upgrade with new technologies
- **Cathode potential O(100 kV)**
- **2% dead mass**
- **Drift time O(1 ms)**

Cathode potential



GLACIER

1-2 MV:

- Feedthrough is a challenge

- Drift time > 10 ms

LAR Purity ~ 0.01 ppb

Accumulation of volume charge

Risk of breakdowns (arcing)

Stored charge ~ $1\text{nF} \times 1\text{ MV} = 1\text{ mC}$

Stored energy $1\text{ mC} \times 1\text{ MV} = \text{1 kJ}$



ARGONCUBE

100 kV

- Feedthrough made at LHEP

- Wide choice of PS units

- Drift time ~ 1ms

Charge attenuation → calorimetry constant term

Purity ~0.1 ppb (reached in ARGONTUBE)

Low distortions (~3%, in MicroBooNE 10%)

~ $1\text{nF} \times 100\text{ kV} = 0.1\text{ mC} / \text{module}$

$0.1\text{ mC} \times 100\text{ kV} = \text{10 J / module}$

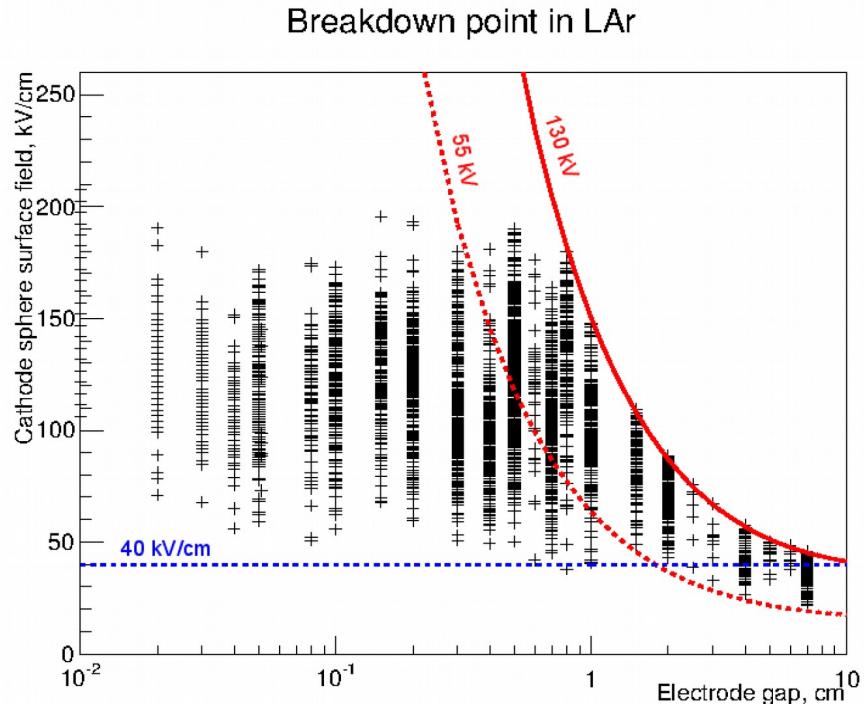
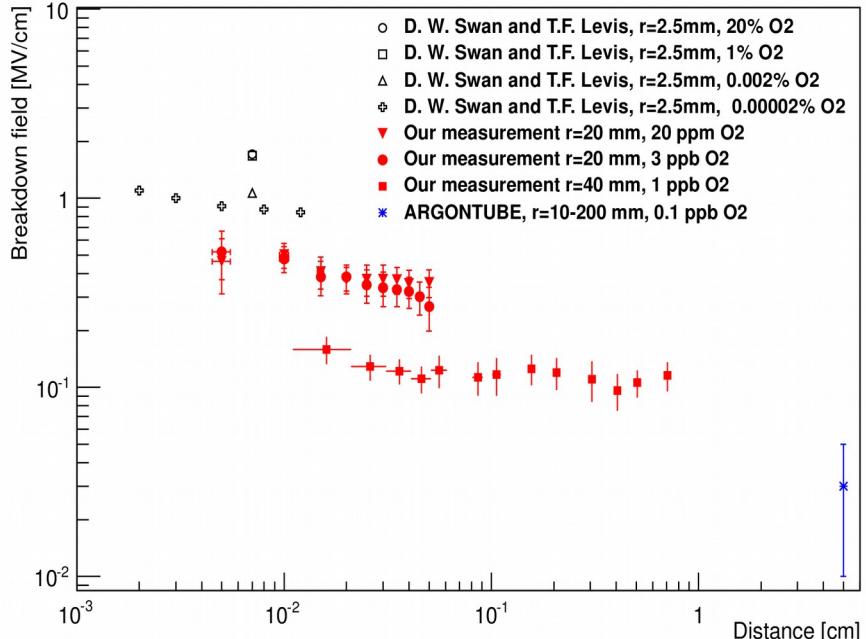
Risk of breakdowns (arcs)

“Experimental study of electric breakdowns in liquid argon at centimeter scale”

A. Blatter, A. Ereditato, C. -C. Hsu, S. Janos, I. Kreslo, M. Luethi, C. Rudolf von Rohr, M. Schenk, T. Strauss, M.S. Weber (U. Bern, AEC) et al.. Jan 26, 2014. 13 pp.
 e-Print: arXiv:1401.6693 [physics.ins-det]

At scales of > 1 cm LAR is not so good dielectric,
 arcing happens already at 40 kV/cm of applied field

ARGONCUBE : safely below 30 kV/cm



ARGONCUBE

Small size prototype

10.10.14 Cryostat is delivered to Bern

Vacuum isolated

Inner volume:

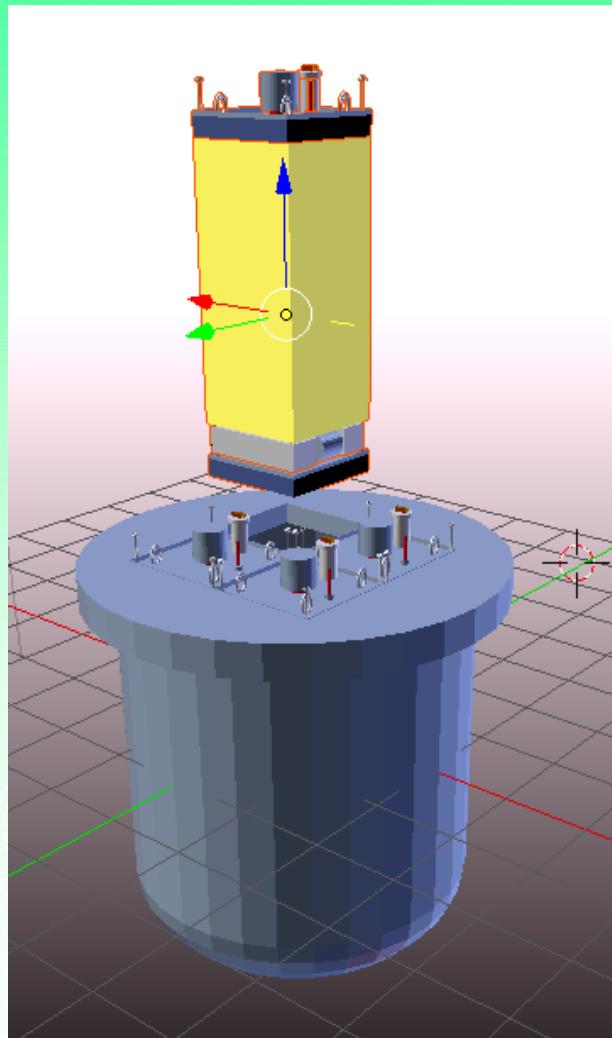
197 cm diameter

180 cm height of cylindrical part



ARGONCUBE

Small size prototype



4 modules

67x67 cm, 1.8m high

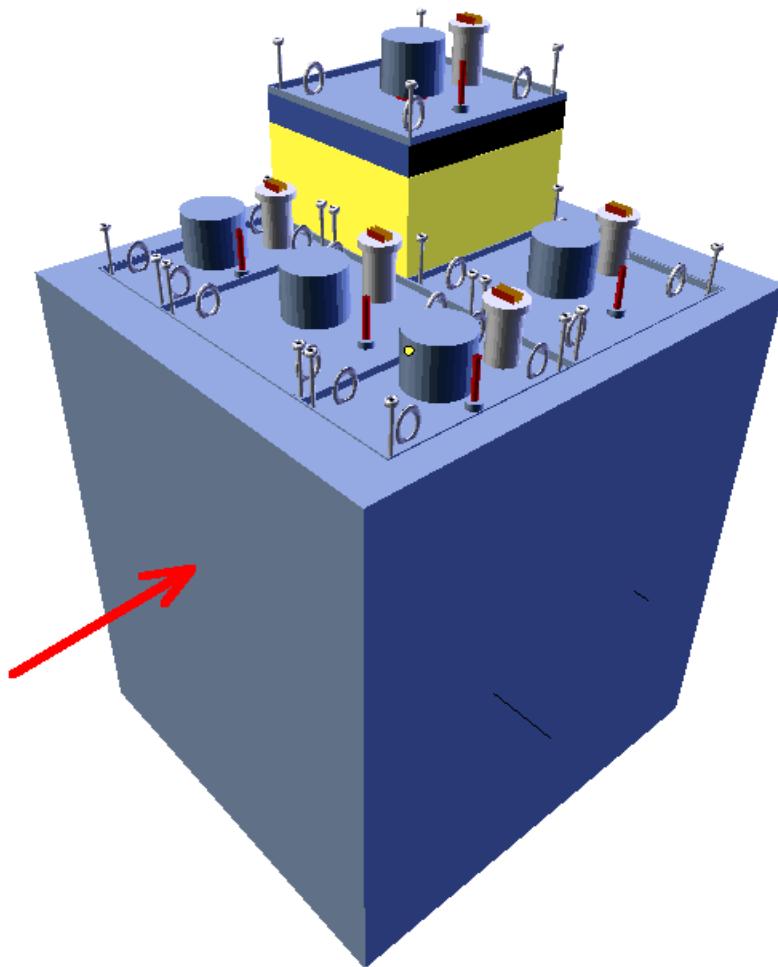
Argon volume $\sim 0.6 \text{ m}^3$ per module

Argon mass $\sim 820 \text{ kg}$ per module

Fiducial mass $\sim 750 \text{ kg}$ per module

ARGONCUBE

Phase2 prototype



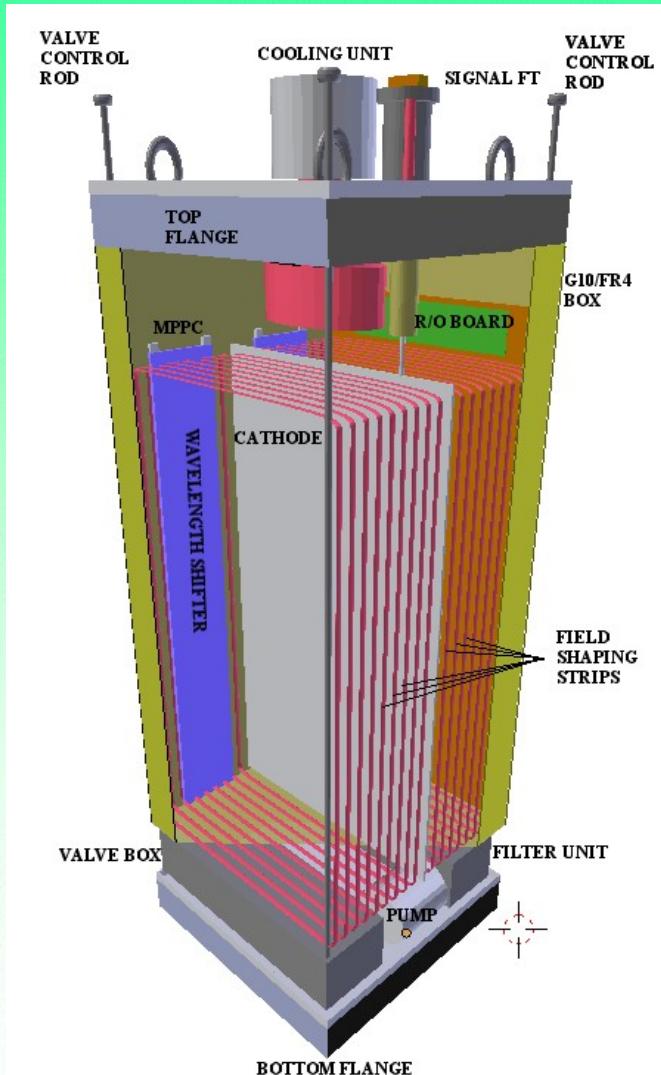
Cryostat 5x5x5 cub.m

5 modules

2x2m (1x2m), 5m high

ARGONCUBE

Small size prototype



TPC module

67x67 cm, 1.8m high

Double-drift scheme

Drift length: 33 cm

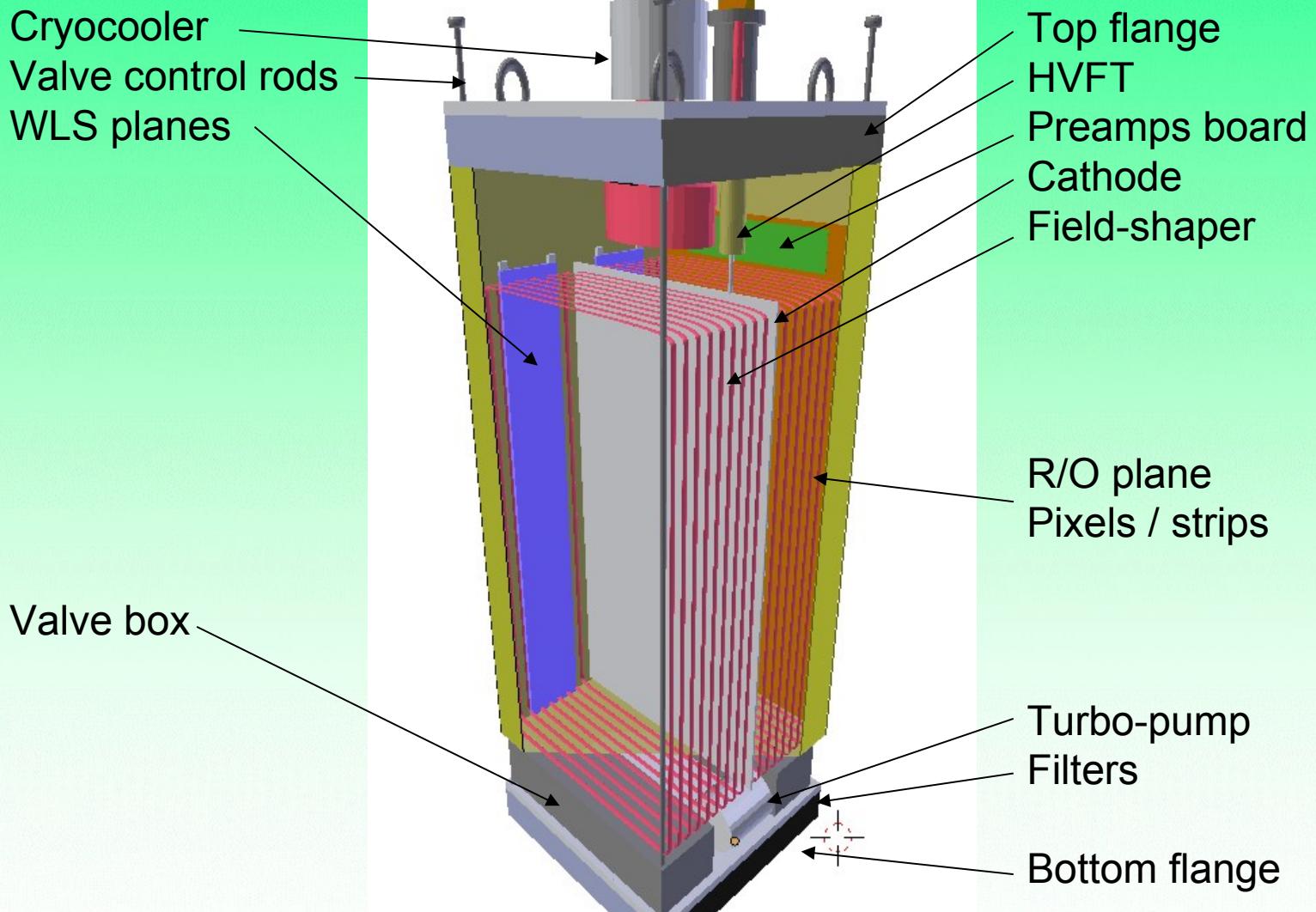
Field cage : copper-in-G10

Scintillation: WLS bar + MPPCs

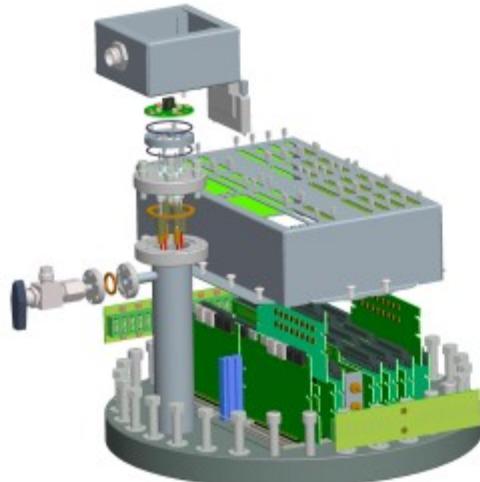
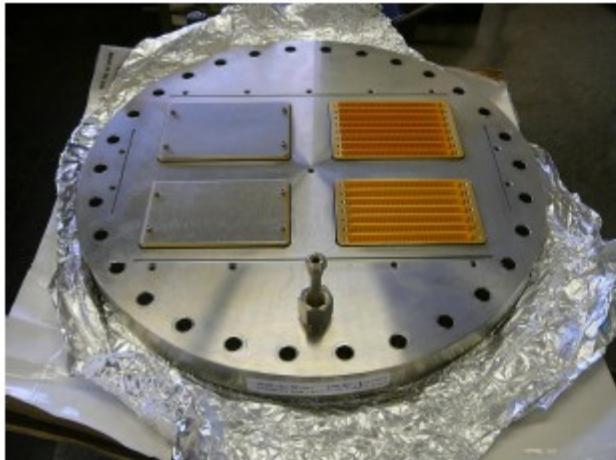
Cryogenic preamps: LARASIC4

ARGONCUBE

Module design



Signal Feed-through



- ATLAS LAr Calorimeter Feed-through
 - Pin carrier welded on flange: 100% hermetic
 - 2x8 + 2x7 rows pin carrier: high signal density 1920-pin/FT
 - Designed for both warm and cold flanges
- MicroBooNE adopted same pin carrier design for 11 warm signal feed-throughs
- Technology exist: no development required
- Pin carrier has been tested to be capable of running at 2 Gb/s

Coaxial structure

Insulator: PET-C

Stainless steel conductors

Tested in LAr at up to 130 kV

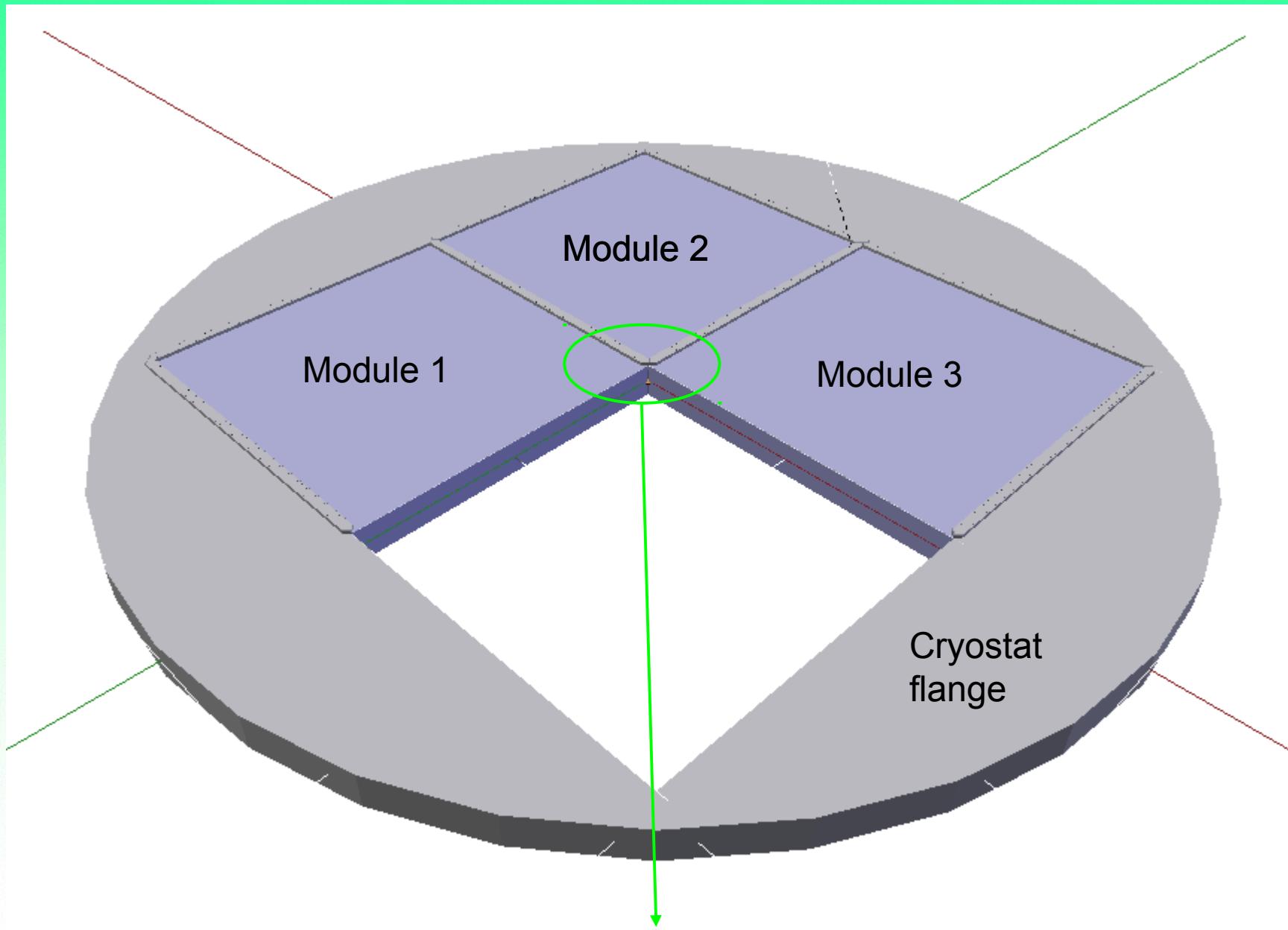
Used for several weeks for study
of breakdowns in LAr

Multiple cool-down/ warm-up
cycles



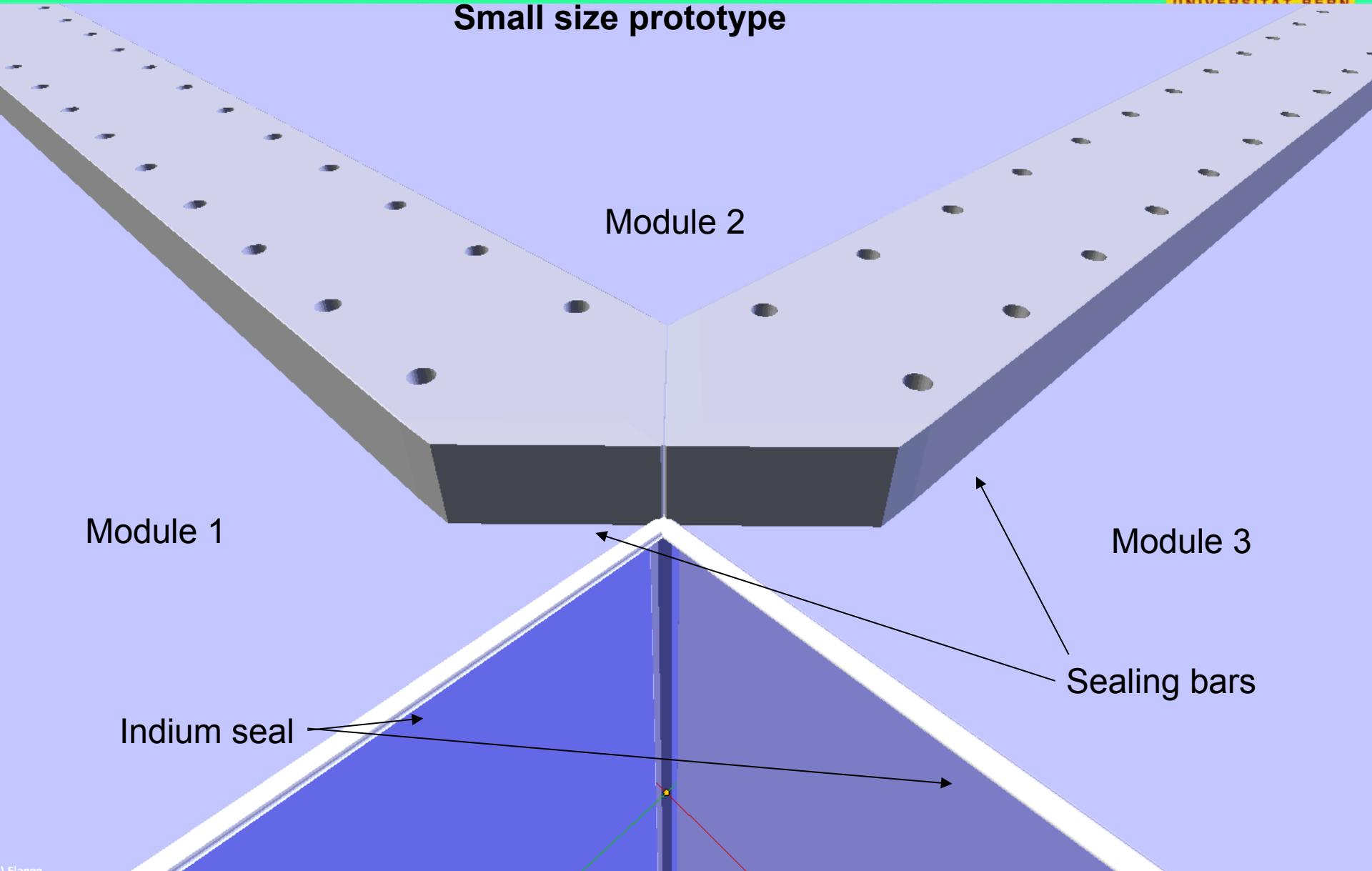
ARGONCUBE

Small size prototype



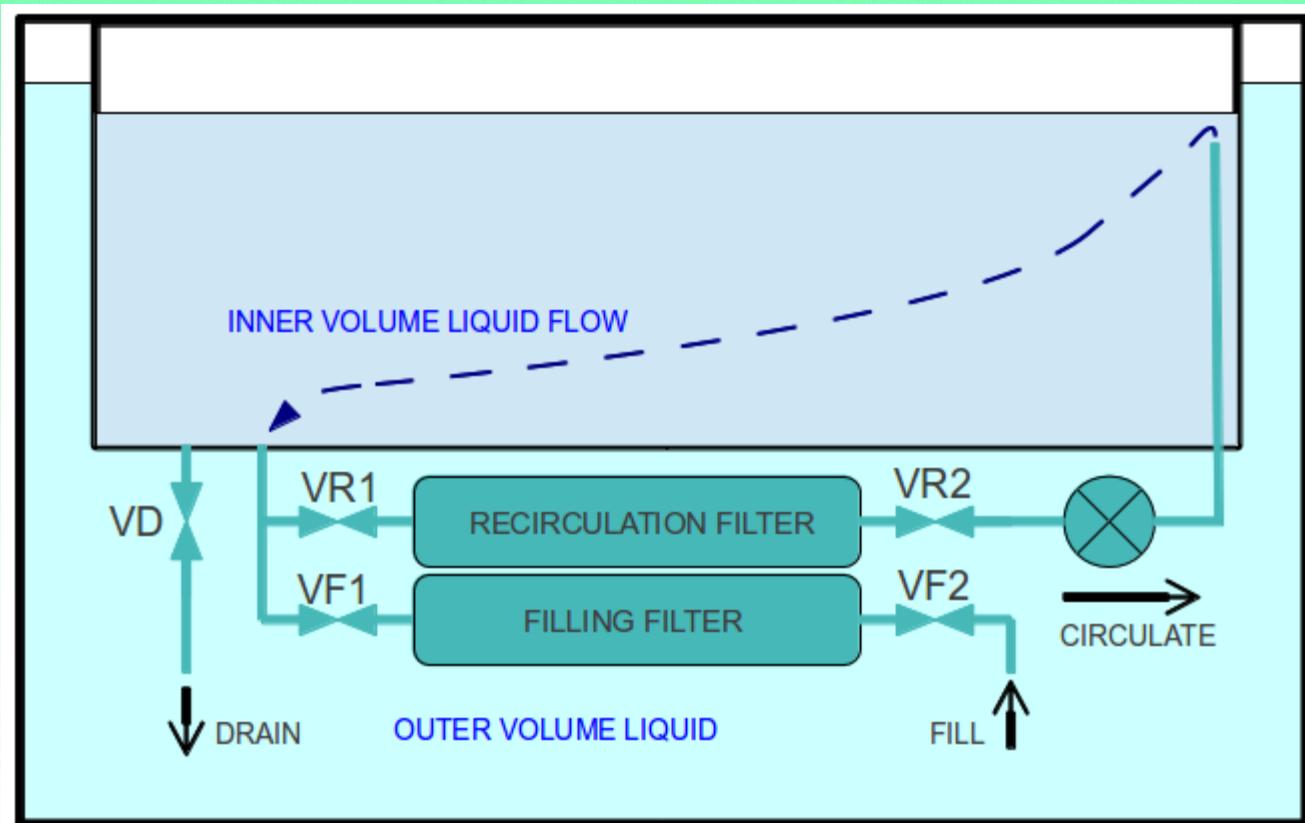
ARGONCUBE

Small size prototype



ARGONCUBE

Liquid argon flow diagram



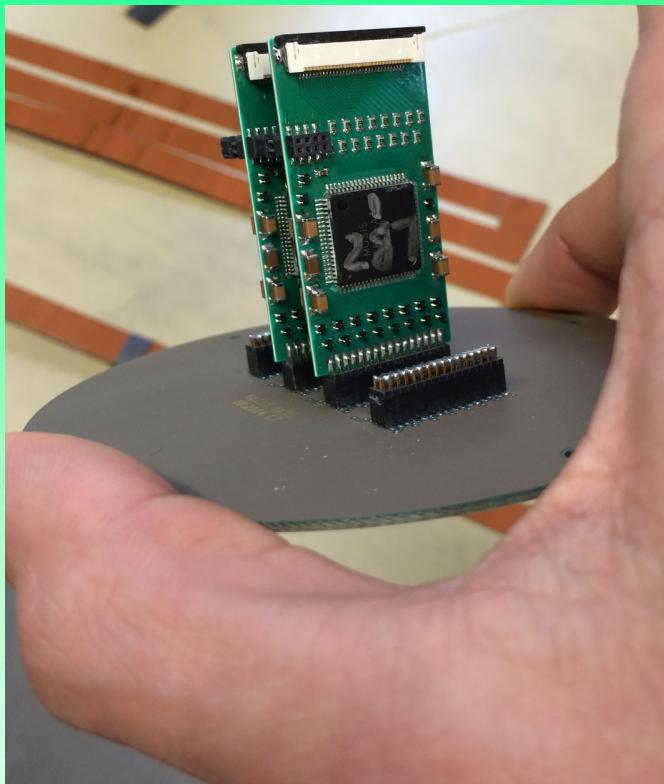
1. Top flange seal removed
2. Top flange unfixed from neighbors
3. Module lifted until bottom matches top
4. Fix “bottom” flange to neighbors
5. Detach support rods
6. Seal the flange
7. Remove the module

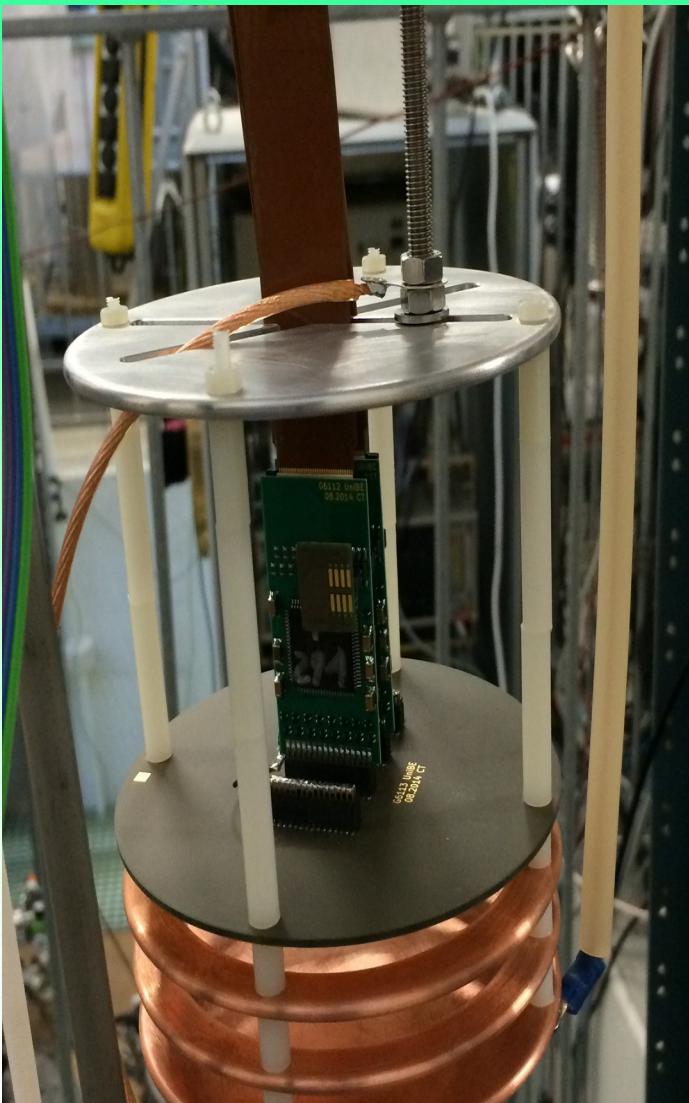
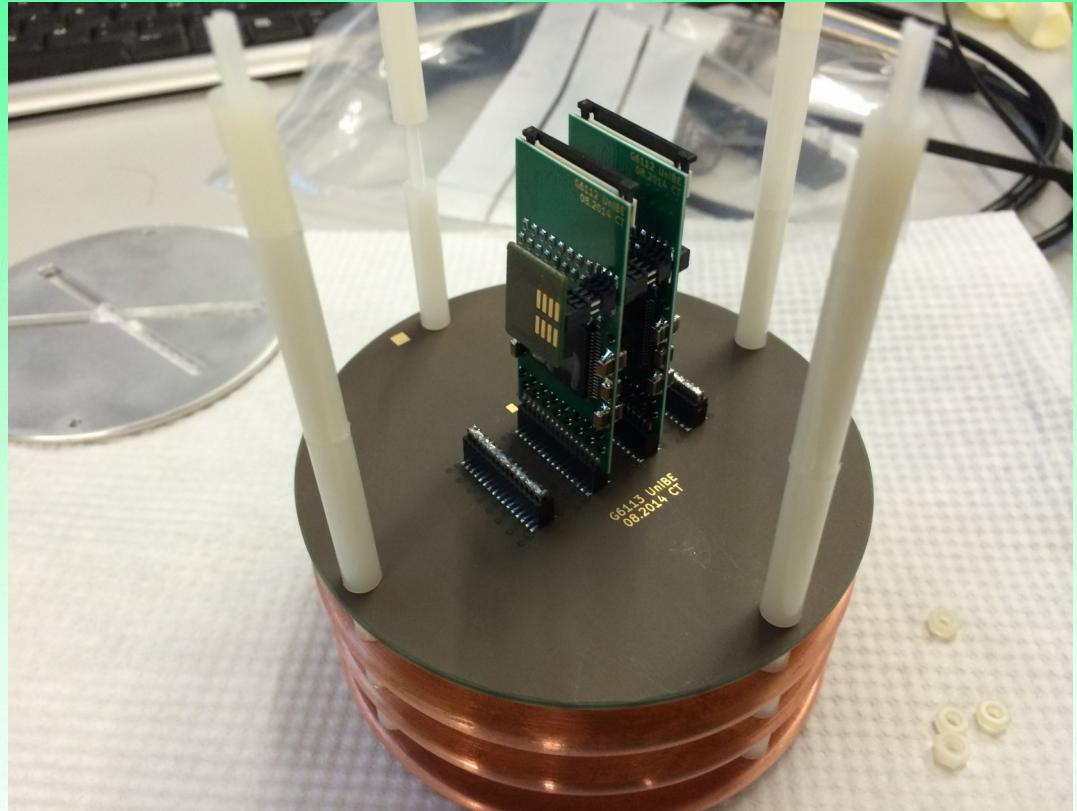
Module lifting : the valves are configured to drain LAr to outer volume

Module insertion : LAr passes from outer volume via filter into module

Operation : LAr is recirculated through the same filter by cryo-pump (turbo, Barber-Nichols)

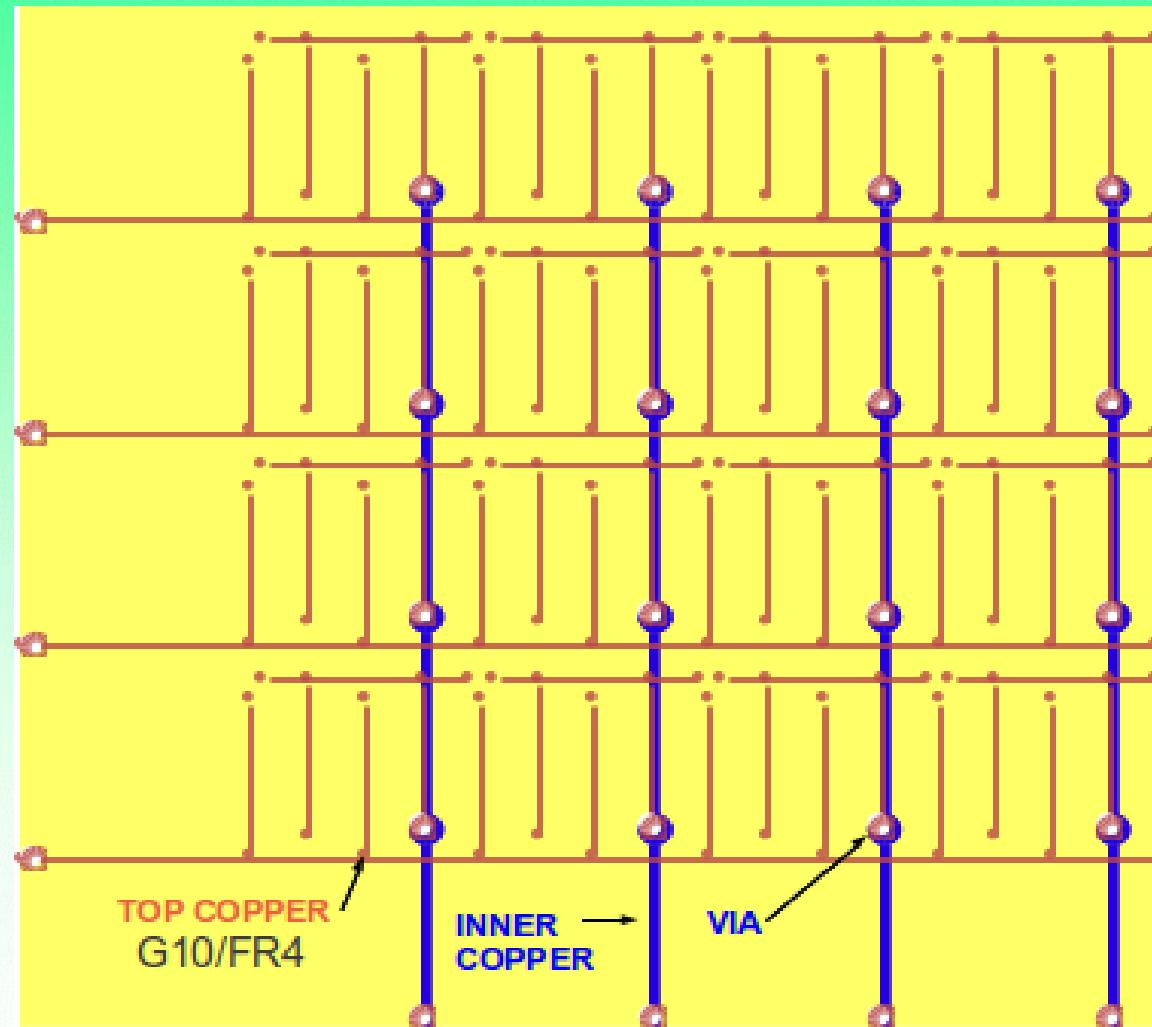
R&D on pixel charge readout





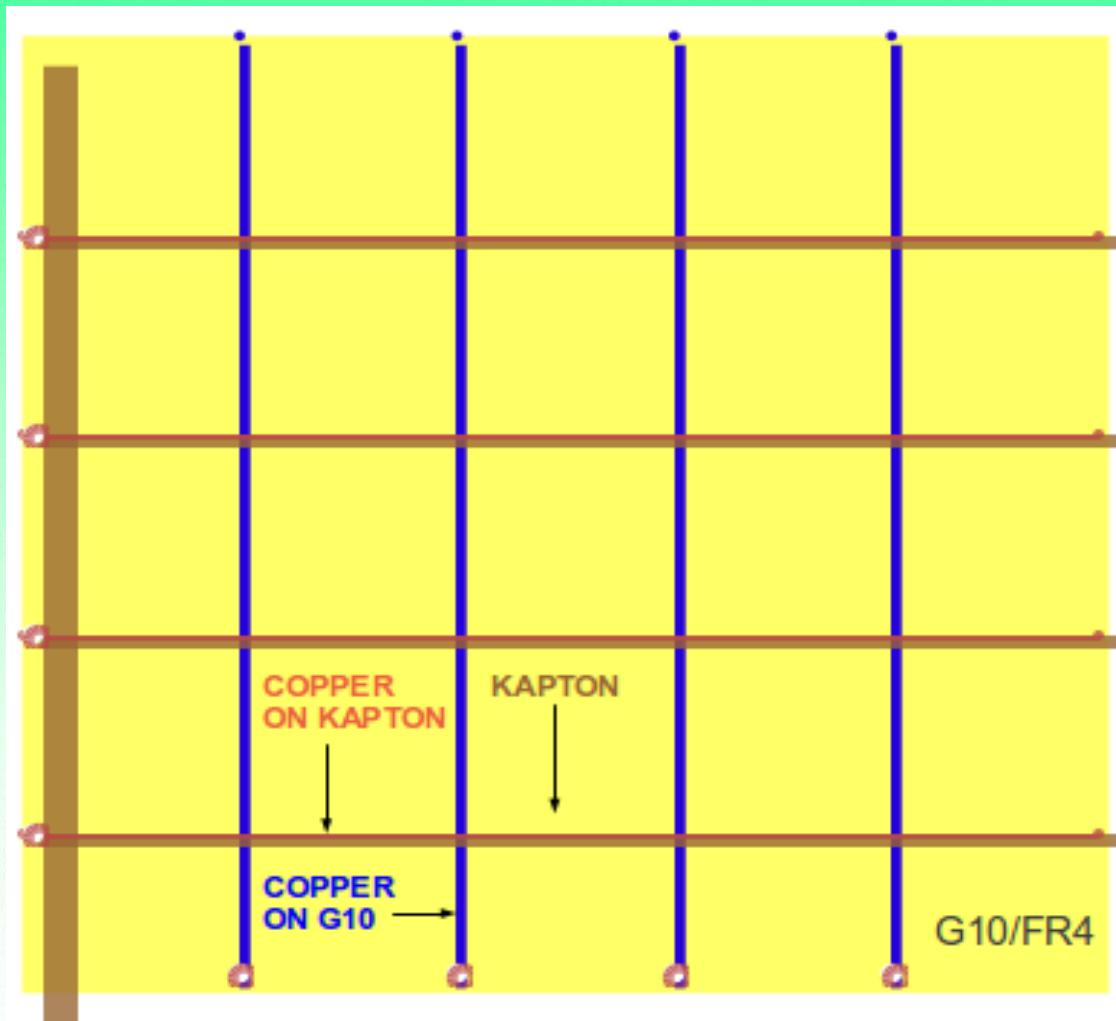
R&D on pixel charge readout

Pattern 1: X-Y shared charge collection



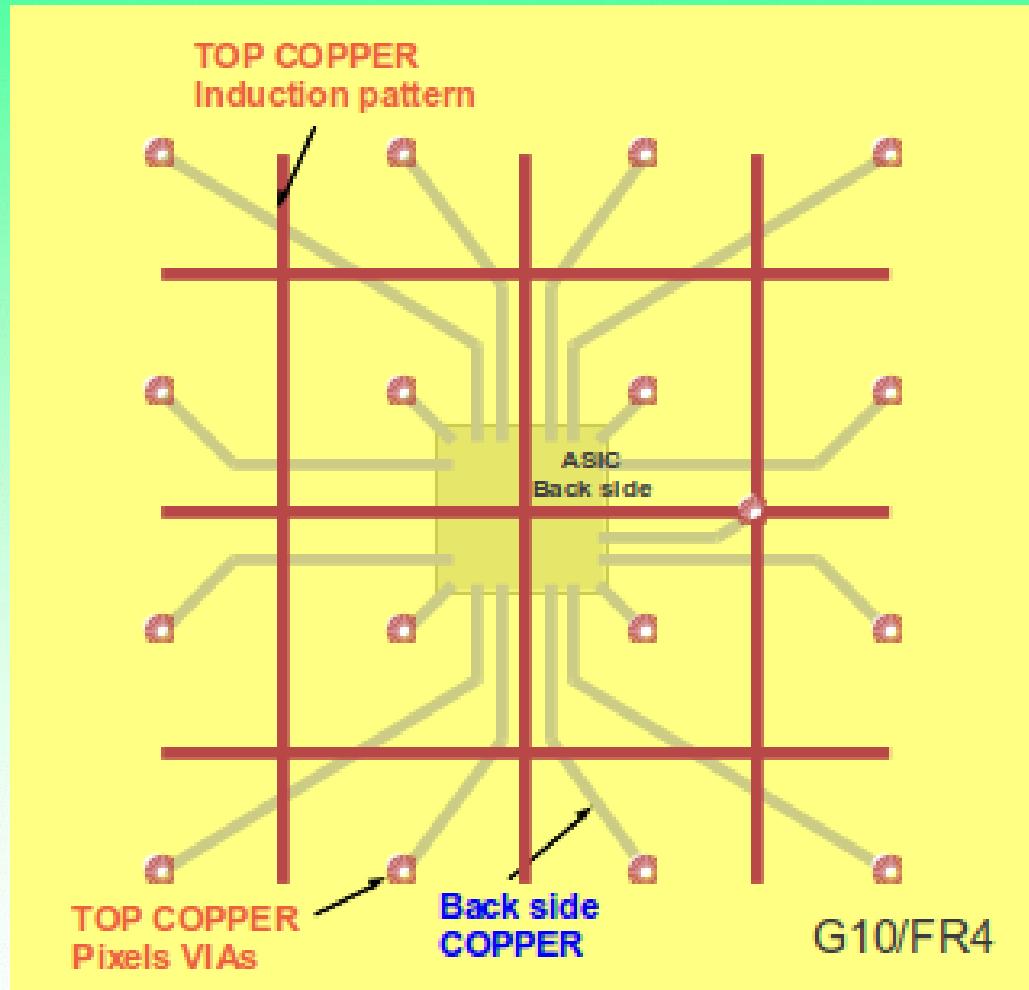
R&D on pixel charge readout

Pattern 2: X-Y shared charge collection



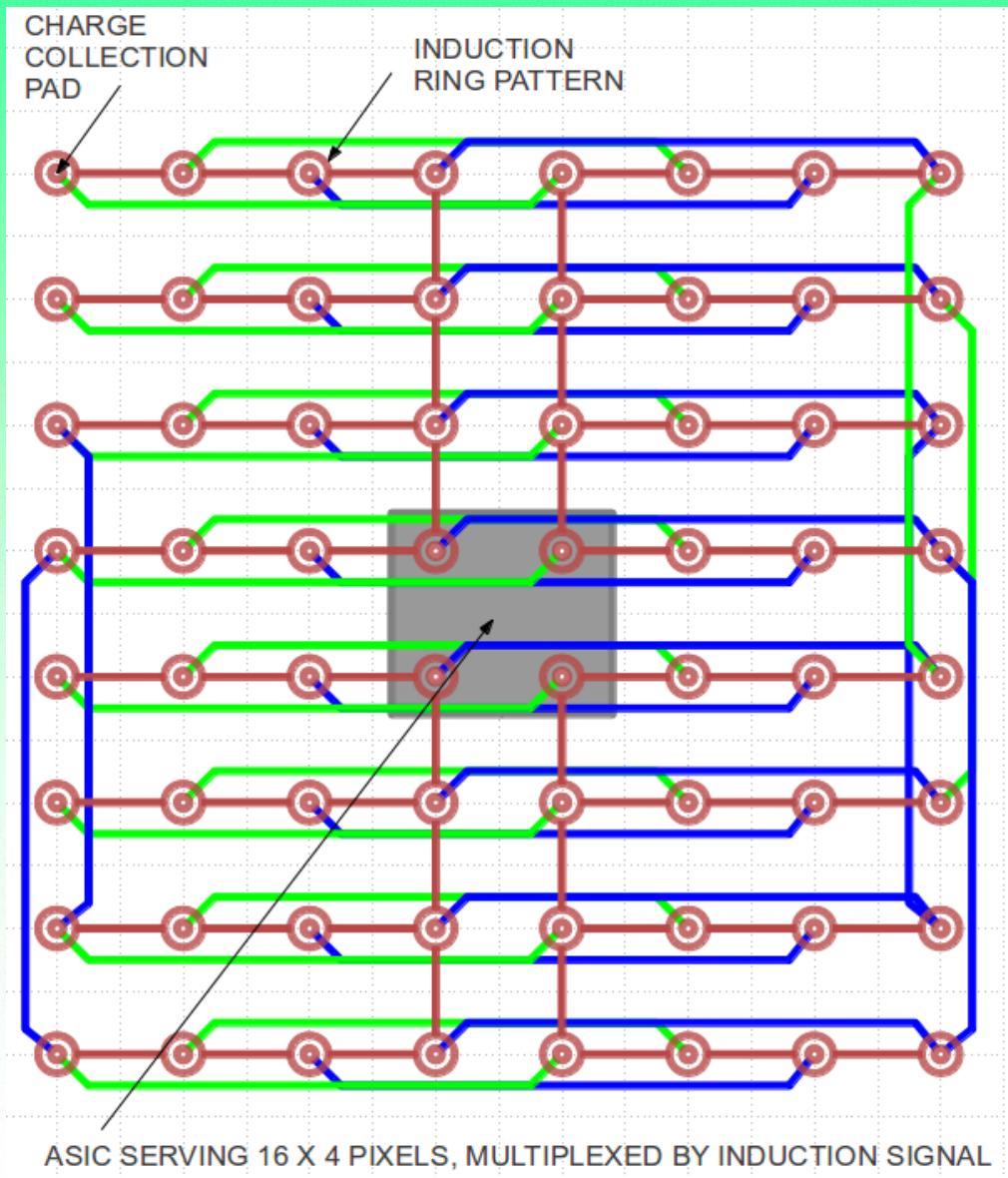
R&D on pixel charge readout

Pattern 3: Pixel charge collection with induction ROI



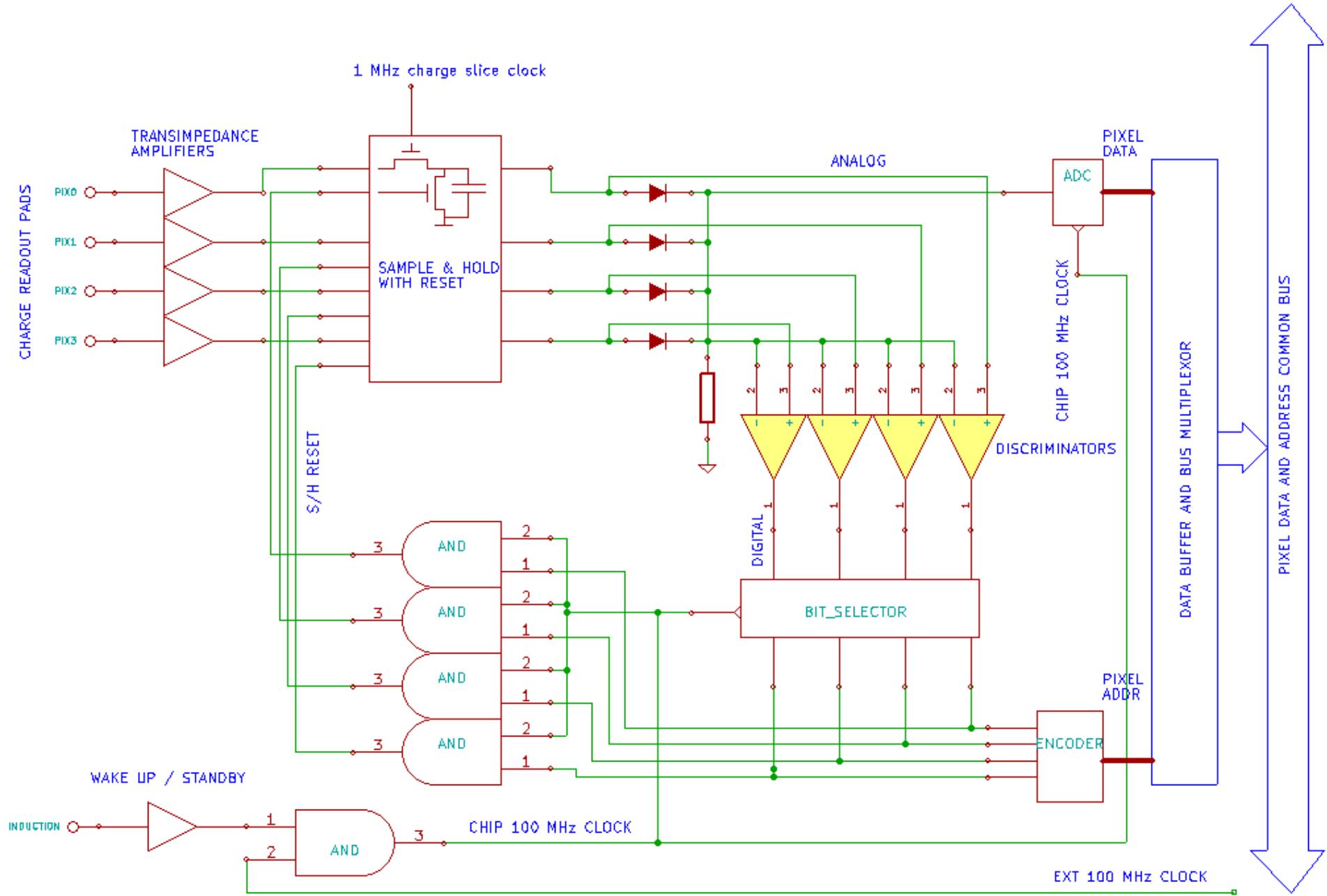
R&D on pixel charge readout

Pattern 4: Pixel charge collection with Improved induction ROI



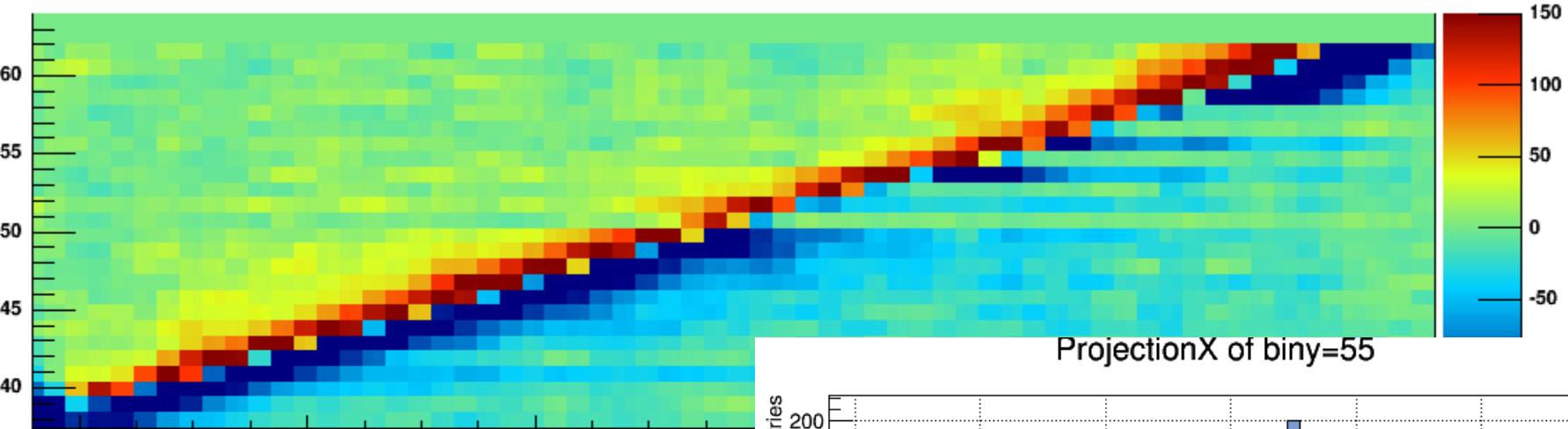
R&D on pixel charge readout

Smart token zero suppression

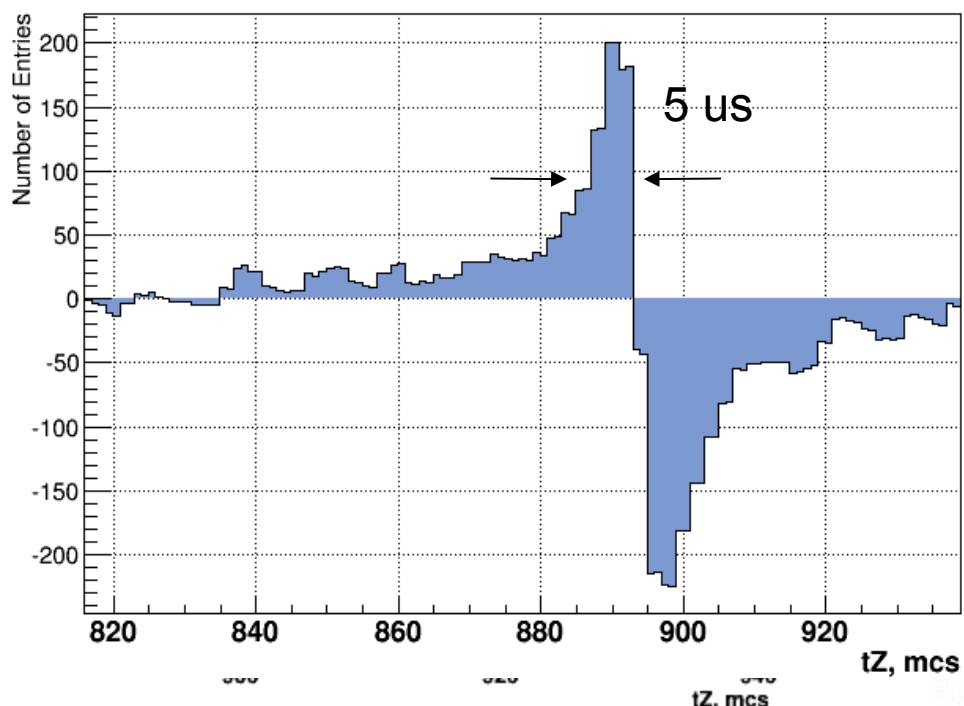


Advance of induction signal → wakeup time

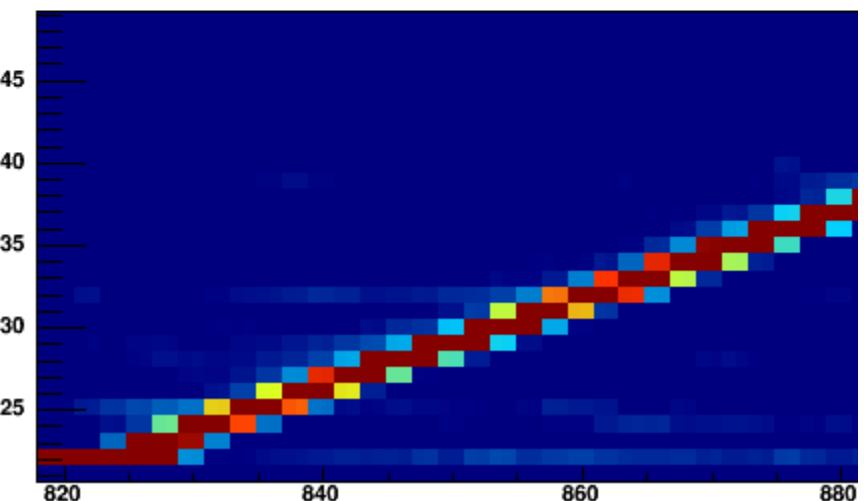
Induction, Run 9136 Event 150. Trigger pattern: I1 I2 T



ProjectionX of biny=55



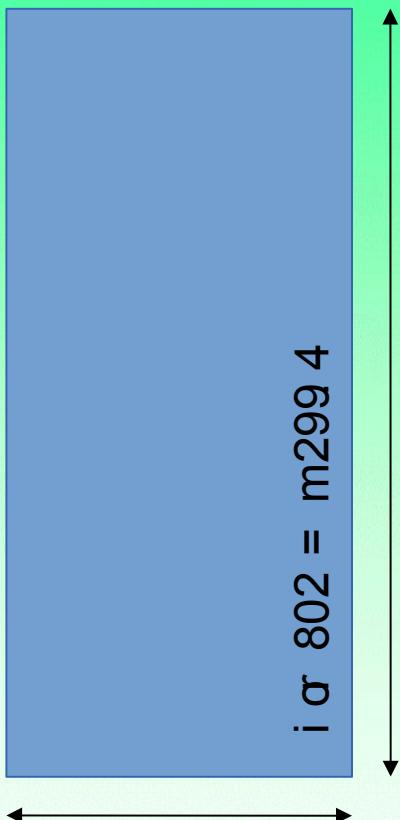
Collection view, Run



3x3 mm pixels



$$8 \text{ pix} = 24 \text{ mm}$$



$$1.992 \text{ m} = 83 \text{ roi}$$

1104896 ch
17264 roi

$m(\text{LAr})=14 \text{ ton}$

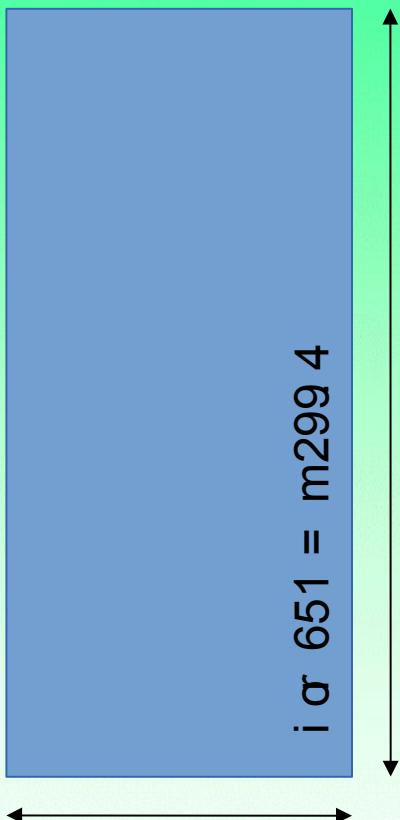
$P_{\text{ch}}=1 \text{ mW/ch} \rightarrow$
 $P_{\text{tot}}=1 \text{ kW}$

79 W/ton of LAr

4x4 mm pixels



$$8 \text{ pix} = 32 \text{ mm}$$



$$1.984 \text{ m} = 62 \text{ roi}$$

619008 ch
9672 roi

$m(\text{LAr})=14 \text{ ton}$

$P_{\text{ch}}=1 \text{ mW/ch} \rightarrow$
 $P_{\text{tot}}=0.6 \text{ kW}$

44 W/ton of LAr

Average power

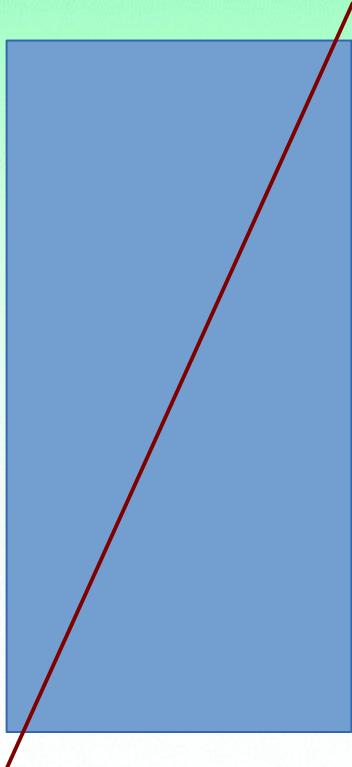
LARASIC4 : 6 mW/ch

Induction channel (always active) 6 mW

Collection channel together with smart-token and ADC : 200 mW/ch (when active)

Assume 1 induction channel per 64 collection channels is always active

For worst scenario, diagonal track:



Total readout window (drift) 1 ms

R/O time slice 1us

Wakeup time 5 us

Average power and data flow

power per ind channel, mW	6	6	6	6
power per full channel,mW	200	200	200	200
APA height, m	5	5	5	5
APA width, m	2	2	2	2
Drift time, ms	1	1	1	1
Time slice, us	1	1	1	1
Drift length, m	1	1	1	1
Argon mass, t	14	14	14	14
pixel size, mm		3	4	5
pixels/roi side	8			
pixels/roi	64	64	64	64
roi side, mm		24	32	40
Nroi/width		83	62	50
Nroi/height		208	156	125
Nroi/plane		17264	9672	6250
Max active roi (diag. Track)		223	167	134
Wakeup time, in time slices	5	5	5	5
<P> per plane, W		117	68	46
<P> per ton of LAr W/ton		8.36	4.86	3.29
Npix per plane		1104896	619008	400000
ADC bits	16	16	16	16
pixel in roi address, bits	6	6	6	6
Time slice number, bits	10	10	10	10
Data, KB per drift (1 track)		446	334	268
Data flow MB/s (1tr/frame)		435	326	261

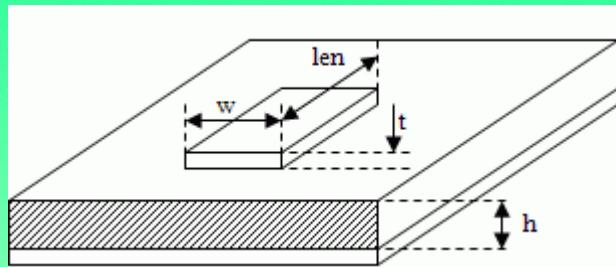


R/O capacitance

Rectangular Pad Capacitance Calculator:

(includes core and fringing capacitance)

$$C = 8.8542 \cdot \epsilon_r \cdot \frac{(w-h) \cdot (l-h)}{h} + 26.40 \cdot (\epsilon_r + 1.41) \cdot \frac{(w+l)}{\ln\left(\frac{5.98h}{(0.8h+t)}\right)}$$



Copper thickness, mm	0.05	0.05	0.05	0.05
Wire width, mm	0.3	0.3	0.3	0.3
Inter-layer thickness, mm	0.2	0.2	0.2	0.2
Pixel size, mm		3	4	5
pixels per roi side	8	8	8	8
Dielectric constant	4.2	4.2	4.2	4.2
Induction pattern length, mm		48	64	80
Induction pattern capacitance, pf		5.00	6.66	8.32
Pixel capacitance, pf		1.97	3.37	5.14

